Clouds and the Earth's Radiant Energy System (CERES)

Validation Document

Validation of CERES Surface Radiation Budget (SRB) (Subsystem 4.6)

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4.6.1 Introduction

4.6.1.1 Measurement & Science Objectives

The CERES subsystem 4.6 endeavor is concerned with the retrieval of both the shortwave and longwave components of the surface radiation budget (SRB) fluxes. The retrieval of surface fluxes is achieved through the use of established parameterized radiative transfer algorithms which derive the surface fluxes directly from top-of-atmosphere (TOA) radiances measured by the CERES instrument aboard satellites such as the Tropical Rainfall Measuring Mission (TRMM), Terra, and Aqua. The CERES SRB direct TOA to surface transfer relationships contrast with the CERES subsystem 5.0 (Surface and Atmospheric Radiation Budget or SARB) algorithms which are based upon complex physical models requiring detailed knowledge of atmospheric conditions. It should be noted, however, that the parameterized transfer algorithms for CERES subsystem 4.6 have been formulated from comprehensive studies involving detailed radiative transfer methods (*e.g.*, line-by-line calculations). The ultimate goal behind the SRB method is to provide reliable yet efficient algorithms applicable to conditions encountered over a substantial portion of the Earth.

To accomplish the goals of CERES subsystem 4.6, separate radiative transfer algorithms have been developed for the shortwave ($\lambda < 5.0\ \mu m$) and longwave ($\lambda > 5.0\ \mu m$) regions of the spectrum. For shortwave radiation, evidence has been presented (see *e.g.*, Cess *et al.*, 1991; Li *et al.*, 1993a) that a straightforward relationship exists between TOA and surface fluxes. This premise forms the basis of the Li *et al.* (1993a) shortwave algorithm which is detailed in Algorithm Theoretical Basis Document (ATBD) subsection 4.6.1 (formerly subsection 2.2.4). A number of studies (see e.g., Cess *et al.*, 1995; Ramanathan *et al.*, 1995; Valero *et al.*, 1997 and Zender *et al.*, 1997), however, suggest that important physical processes may have been overlooked with the consequence that significant contributions to the radiation field may have been neglected. Specifically, these papers present evidence that for total-sky conditions shortwave absorption occurs in excess of that predicted theoretically. The conclusions of their papers are further supported by the fieldwork of Pilewski and Valero (1995) which deals with aircraft measurements of shortwave fluxes made within the cloudy tropical atmosphere. Other studies, (*e.g.*, Arking, 1996) find excess shortwave absorption, but suggest that the unexplained absorption is manifested during clear conditions, and that clouds are not the source of the discrepancy. Additional studies by Li *et al.* (1995) and Chou *et al.* (1995) have been unable to discern any significant shortwave flux discrepancies and thus do not support the conclusions of enhanced shortwave absorption. Thus, until a comprehensive determination is made, the Li *et al.* (1993a) shortwave algorithm will continue to be used as the CERES SRB shortwave algorithm. Resolving the enhanced shortwave absorption issue is part of the validation effort which depends upon the acquisition of data from field campaigns such as the ARM (Atmospheric Radiation Measurement) Enhanced Shortwave Experiment (ARESE), and from operational surface networks such as the NOAA Surface Radiation (SURFRAD) network in the U.S. and the World Climate Research Program (WCRP) Baseline Surface Radiation Network (BSRN). In addition, a compilation of CERES and ARM data sets has been created as part of the CERES subsystem 5.0 validation effort. Known as CAVE (CERES/ARM Validation Experiment), these data sets are critical to the success of the CERES subsystem 4.6 validation effort.

For longwave radiation no algorithm has been successful in retrieving the net surface flux directly from the TOA flux. While the difficulties are substantial for clear-sky conditions, they are particularly vexing for total-sky conditions where strong longwave absorption in clouds results in a complete decoupling of the TOA and surface longwave radiation fields (Stephens and Webster, 1984). Nevertheless, as noted by Gupta *et al.* (1994), by taking into consideration certain meteorological parameters, a successful alternative approach can be formulated to obtain the surface fluxes. Indeed, two successful algorithms have been developed, one for the clear-sky case, and one for the total-sky case. The Inamdar and Ramanathan (1994) algorithm, detailed in ATBD subsection 4.6.2, calculates the surface fluxes for clear-sky conditions using the meteorological parameters in combination with the TOA infrared window radiances obtained from the CERES 8.0—12.0 μm channel, and TOA longwave radiances derived from the CERES Total and Shortwave channels. This clear-sky longwave algorithm is therefore in a position to take full advantage of the CERES measurements. For total-sky conditions, Gupta (1989) has developed an algorithm, detailed in ATBD subsection 4.6.3, which has proven useful in retrieving surface fluxes for clear and cloudy conditions (see also Gupta *et al.* (1992)). The longwave validation effort will use many of the data sets being used in the shortwave validation effort.

4.6.1.2 Missions

A single CERES instrument was flown aboard the Tropical Rainfall Measuring Mission (TRMM) satellite. Two CERES instruments are currently flying aboard the Terra platform and another two are scheduled to be launched aboard the Aqua platform. An additional CERES instrument is awaiting assignment to a future flight. The CERES science team is also working towards the possibility of flying CERES or a CERES follow-on instrument aboard the next generation of Earth resource/science satellites.

4.6.1.3 Science Data Parameters

The selected algorithms will provide data parameters as part of the Single Satellite Flux (SSF) data product by calculating each of the surface radiation budget flux components, namely: shortwave, clear-sky longwave, and total-sky longwave. The input data for these algorithms are provided by three sources: CERES TOA fluxes for each footprint, MOA (Meteorology, Ozone and Aerosols) meteorological data, and CERES cloud properties for each footprint. Overviews of the three models have been presented in the CERES ATBD. Specifically, the Li *et al.* (1993a) shortwave algorithm is discussed in subsection 4.6.1 (formerly subsection 2.2.4), the Inamdar and Ramanathan (1994) clear-sky longwave algorithm is discussed in subsection 4.6.2, and the Gupta (1989) total-sky longwave algorithm is discussed in subsection 4.6.3. The input parameters required and output parameters provided by the algorithms are as follows.

a) Shortwave: The input parameters required by the Li *et al.* (1993a) shortwave algorithm include: the CERES instrument measurements of the reflected TOA shortwave flux (Wm^{-2}) and solar zenith angle, and the MOA values for the precipitable water (g cm^{-2}). It is important to note that no information is required concerning either the surface conditions or the presence/absence of clouds. The output of this routine is the net shortwave flux at the surface (Wm^{-2}).

b) Longwave Clear-Sky: The input parameters required by the Inamdar and Ramanathan (1994) longwave clear-sky algorithm include: the CERES instrument measurements of the clear-sky TOA longwave broadband ($\lambda > 5.0\ \mu m$) flux (Wm^{-2}) and the clear-sky TOA longwave window (8.0—12.0 μm) flux (Wm^{-2}), and the MOA values for the surface temperature (K), atmospheric temperature profile (K), total column precipitable water vapor (g cm^{-2}) and aerosol visible optical depth. Another potentially important input, the surface emissivity, will be taken into consideration by using the Wilber *et al.* (1999) surface emissivity maps. The output includes: downward longwave broadband ($\lambda > 5.0\ \mu m$) surface flux (Wm^{-2}), downward longwave window (8.0—12.0 μm) surface flux (Wm^{-2}), and downward non-window surface flux (Wm^{-2}).

c) Longwave Total-Sky: The input parameters required by the Gupta (1989) longwave total-sky algorithm that are derived from the MOA values include: the surface temperature (K), the atmospheric temperature profile (K), the atmospheric water vapor amount (g cm^{-2}). In addition, the Gupta (1989) algorithm requires the following CERES Footprint and Cloud Properties values: fractional cloud amount, cloud base pressure (hPa), cloud top pressure (hPa), and cloud top temperature (K). As with the Inamdar and Ramanathan (1994) algorithm, the Gupta (1989) algorithm will incorporate the Wilber *et al.* (1999) surface emissivity maps. The output from the Gupta (1989) algorithm includes: downward longwave surface flux (Wm^{-2}) and net longwave surface flux (Wm^{-2}).

4.6.2 Validation Criterion

4.6.2.1 Overall Approach

In order to have confidence in the output of CERES subsystem 4.6, it is necessary to establish validation criteria to determine an algorithm's reliability for the proposed task. Validation of the CERES subsystem 4.6 algorithms depends upon the availability of simultaneous TOA and surface measured net fluxes in both the shortwave and longwave portions of the spectrum, as well as the availability of information concerning atmospheric temperature and water vapor abundance. These validation measurements are to be provided by a combination of long term programs and specialized field campaigns, which are either underway or have been proposed. Recall that CERES subsystem 4.6 and 5.0 process the input data quite differently; however, both subsystems output shortwave and longwave surface fluxes. Thus, it is instructive to compare the appropriate results of these two subsystems when they are applied to the same input data.

4.6.2.2 Sampling Requirements & Trade-offs

The surface fluxes derived by the CERES subsystem 4.6 algorithms are subject to systematic and random errors arising from two fundamental sources: the algorithm itself and the data input into the algorithm. Errors associated with the algorithm may arise from an imperfect understanding of the involved radiative transfer processes or from the inherent deficiencies of any parameterization that utilizes simplified treatments to describe complex processes. Errors associated with the input data include: calibration, radiance to flux conversion, water vapor abundance estimates, etc. The diversity of error sources necessitates the determination of not only the magnitude of the error but also its origin. Identifying the error sources allows for continual improvement in the accuracy of the algorithm. With this in mind, information should be gathered not only for those parameters required in the current algorithms but also for those that have potential impact on the retrieval and are not included in the current versions of the algorithms. Since many of the relevant parameters remained unavailable until the CERES instrument became operational, the pre-launch validation emphasized the documentation of the uncertainties under very diverse conditions. Post-launch validation has therefore been concerned with identifying the sources of uncertainties and improving the algorithms. In addition, it is necessary to clearly specify whether the surface fluxes are derived from instantaneous or time-averaged measurements, and whether the quoted errors are systematic which yields information on accuracy (bias), or random which yields information on precision (variance). For present purposes, measurements with time scales of order one hour or less are considered to be instantaneous, while measurements with time scales of order one day or longer are considered to be time-averaged.

4.6.2.3 Measures of Success

Table 1 lists achievable accuracy goals for the ATBD 4.6 output parameters. As noted by Suttles and Ohring (1986), a root mean square error of ± 20 Wm^{-2} for instantaneous retrievals and ± 10 Wm^{-2} for gridded monthly averages is considered desirable for both shortwave and longwave surface fluxes. With the acquisition of information during the post-launch phase, and with continual improvements to the algorithms, it is quite possible that a factor of two improvement over the accuracy goals in Table 1 may be attainable.

Table 1. ATBD 4.6 Accuracy Goals

Parameter	Instantaneous (Wm^{-2})	Monthly Average (Wm^{-2})
Total-Sky Shortwave	± 20	± 10
Clear-Sky Longwave	± 20	± 10
Total-Sky Longwave	± 20	± 10

More definitive accuracy goals, than those presented in Table 1, are dependent upon the errors incurred in obtaining and processing the TOA measurements, the errors associated with the required ancillary data sets, and the inherent errors created during the use of the radiative transfer routines. In addition, the accuracy goals are dependent upon the scientific requirements articulated by the investigators who will use the derived surface fluxes. To clarify the issue, assume that an investigator requires the errors in the derived surface fluxes to be contained within a certain range in order to obtain meaningful results. If the range of acceptable errors does not encompass the errors incurred during data collection and processing then the results will be compromised. Thus, either the investigator's requirements must be relaxed or the data collection and processing techniques must be improved. It is therefore absolutely critical to specify the accuracy requirements placed upon the simulated surface fluxes as well as the calculated tolerances. It should be noted, however, that as new uses are devised for the retrieved surface fluxes, the accuracy requirements for the data may necessarily need to be modified.

4.6.3 Pre-launch Algorithm Test/Development Activities

4.6.3.1 Existing Validation Studies

The authors for each of the ATBD 4.6 algorithms have already reported results detailing activities in support of the applicability of the ATBD 4.6 algorithms. The results, however, are difficult to fully interpret since the comparisons were performed against widely different data sets, and little information was provided concerning the error analyses. Thus, there exists a critical need for a comprehensive program which compares the model outputs using specified TOA measurements to corresponding ground based measured net surface fluxes. Fulfilling this critical need will alleviate much of the ambiguity that exists concerning the accuracy of the algorithms. Before detailing such a program, it is useful to review the results reported in support of the CERES subsystem 4.6 models.

The Li *et al*. (1993b) shortwave algorithm has been tested by comparing the net surface flux deduced from broadband radiance measurements from Earth Radiation Budget Satellite (ERBS) against surface data from two sets of tower measurements. The comparisons indicate that errors in the monthly mean surface insolation can be anticipated to have biases near zero with root mean square errors between 8 and 28 Wm^{-2}. The root mean square errors are associated principally with poor representation of surface observations within a grid-cell, and thus, with a sufficient number of observations, it is estimated the root mean square errors could be within 5 Wm^{-2} (Li *et al*., 1995). Thus, as noted by Li *et al*. (1993b) it is reasonable to expect the uncertainty in the global climatology of the surface solar radiation budget to be well within 10 Wm^{-2}. For an individual estimate corresponding to a particular region and month, however, the uncertainty is less well defined because relatively large amounts of noise (as a result of mis-match) are superimposed upon relatively weak signals. So far all of the validations which have been undertaken suffer from this mis-match problem. Concurrent and co-located observations from space, at the surface, and in the atmosphere are keys to the success of future validations. At the same time, it is possible to detect the influence of certain parameters on the retrieval of the surface radiation budget, if these parameters vary over large scales. For instance, Li (1995) analyzed regional variation of estimation error with respect to the spatial variation of aerosol, using data from the existing global radiation network. Li found that biomass burning and desert dust have considerable impact on the retrieval of the surface radiation budget under clear-sky conditions. Presence of clouds lessens the estimation error considerably. This is rather encouraging, as aerosol information is generally available under clear-sky conditions. Because of the limited availability of observational data and the skewed distribution of radiation stations, the Li *et al.* (1993b) algorithm was also evaluated indirectly using an independent satellite-based data set (Li, 1995). While none of the estimation data is sufficiently reliable to be regarded as “ground-truth,” a given set may be superior to others in certain respects. Such an indirect validation may help identify several potential sources of uncertainty which await further confirmation from future validations. The validation efforts of Li *et al.* (1995) have indicated that the Li *et al.* (1993b) algorithm works better in the mid-latitude than in the tropical and polar regions. It must be noted, however, that because of the limited number of observations, the magnitude of the error estimates for the tropics and polar region is far worse than that established for the mid-latitudes.

The current version of the Inamdar and Ramanathan (1994) clear-sky longwave algorithm was formulated to take advantage of TOA radiance information for both the window (8.0—12.0 μm) and non-window spectral regions. In addition to input from CERES broadband and window channel measured TOA radiances; the Inamdar and Ramanathan method is dependent upon surface and near surface (950 hPa) atmospheric temperature data, and total column water vapor measurements. The primary source for the total column water vapor data is the Special Sensor Microwave Imager (SSM/I) aboard the Defense Meteorological Space Program (DMSP) satellites. The total column water vapor can also be obtained from the detailed water vapor profiles derived from measurements by the Special Sensor Microwave Water Vapor Profiler (SSM/T-2) aboard the

DSMP satellites, or by the TIROS Operational Vertical Sounder (TOVS). When compared to detailed radiative transfer models, the Inamdar and Ramanathan clear-sky longwave algorithm yields root mean square errors of approximately 4.4 Wm^{-2} for the tropics and 3.2 Wm^{-2} for the extra-tropics. Moreover, Inamdar and Ramanathan reveal that a comparison of their algorithm results to detailed radiative transfer calculations yields a very high correlation (0.9998) along with a regression line close to 45 degrees which indicates the absence of any bias in the parameterized estimates.

In addition to comparing their algorithms to a detailed radiative transfer model, Inamdar and Ramanathan (1994) have undertaken validation exercises which consider data from the Central Equatorial Pacific Experiment (CEPEX) conducted in March/April 1993, and measurements from the Intensive Observation Period (November 1992—February 1993) at Kavieng Island taken as part of the Tropical Oceans and Global Atmosphere/ISS (TOGA/ISS) program. CEPEX utilized Fourier Transform Infrared Spectroradiometer (FTIR) measurements which were made of the incoming longwave radiances in the 5—20 μm. region. In addition, broadband longwave fluxes were measured with an Eppley Pyrgeometer. Despite certain shortcomings (see Inamdar and Ramanathan, 1994), the results from the standard model agree fairly well with the FTIR and Pyrgeometer measurements. Inamdar and Ramanathan have noted, however, that there are systematic differences between FTIR and the collocated Pyrgeometer measurements that suggest calibration-related uncertainties in the FTIR of 5—8 Wm^{-2}. With respect to the broadband flux measurements taken at Kavieng Island, the algorithm compares favorably with mean differences of 3 Wm^{-2} and root mean square differences of approximately 10 Wm^{-2}.

Inamdar and Ramanathan (1994) have further noted that thick haze in the atmospheric boundary layer (horizontal visibilities < 15 km) has the potential to increase the downward flux by 3 to 5 Wm^{-2}. Measurements taken at the ARM sites in Oklahoma and Kavieng tend to confirm this observation, and thus, Inamdar and Ramanathan intend to modify their algorithms with an additional parameter in the form of aerosol visible optical depth. Gupta *et al.* (1993) conducted sensitivity studies for the total-sky longwave algorithm that demonstrated that most of the errors in the surface longwave fluxes arose from the errors in the input meteorological data.

Gupta *et al.* (1993) found, however, that accuracy goals comparable to those presented in Table 1 are achievable over most tropical and mid-latitude areas. In contrast, Gupta *et al.* (1993) noted that errors over desert and snow/ice-covered areas in the Polar Regions are considerably higher, reaching 30—40 Wm^{-2} for instantaneous retrievals and 20 Wm^{-2} for gridded monthly values. Nevertheless, Gupta *et al*. (1993) concluded that, with the steady improvements expected in the accuracy of the input meteorological data, it should be possible to meet or exceed the accuracy goals suggested in Table 1 over all regions of the globe.

4.6.3.2 Operational Surface Networks

While the previously reported error analyses are informative, a thorough investigation of the applicability of the CERES subsystem 4.6 routines is dependent upon the availability of simultaneously measured TOA satellite radiances and surface net fluxes for both the shortwave and longwave portions of the spectrum. In addition to accurate measurements of TOA radiances and surface fluxes, coincident measurements of temperature and humidity profiles, and cloud properties are necessary for validation. Although limited in extent, a validation data set has already been produced from measurements taken at the Atmospheric Radiation Measurement/Cloud and Radiation Testbed (ARM/CART) Southern Great Plains (SGP) site in Lamont, Oklahoma during the ARM Intensive Observing Period (IOP) in April 1994, and is available through the CERES/ARM/GEWEX experiment (CAGEX) at NASA/LaRC. What satellite data was taken? The CAGEX database provides measurements taken at the SGP site concerning surface shortwave and longwave fluxes. Interpolation of the nearby soundings from the National Weather Service network provides coincident temperature and humidity profiles over the site. While the CERES Cloud Working Group provides information on the cloud properties retrieved from GOES data. As noted previously, a compilation of the CERES and ARM data sets have also been created and incorporated as CAVE (CERES/ARM Validation Experiment). The CAVE data sets should prove very useful for the CERES subsystem 4.6 and subsystem 5.0 validation efforts. A pre-launch campaign, ARESE, was undertaken during the fall of 1995 at the SGP site (see e.g., Valero *et al.*, 1997, and Bush *et al.*, 1999). ARESE was principally designed to provide information addressing important issues concerning the magnitude of shortwave absorption in clouds. Nevertheless, ARESE also provided the opportunity to gather additional surface-measured shortwave and longwave fluxes along with coincident meteorological data which can be incorporated into the CAGEX data base and thus can be used for pre-launch validation.

4.6.3.3 Existing Satellite Data

It should be noted that any validation activity which uses satellite radiance data collected after ERBE and before CERES has an inherent source of uncertainty arising from the lack of TOA broadband measurements While narrowband measurements can serve as surrogates, calibration and bi-directional reflectance effects lead to unquantified errors.

4.6.4 Post-launch Activities

4.6.4.1 Planned Field Activities & Studies

For post-launch validation, the collection of high quality surface measurements will continue at the SGP site and will be initiated at the Tropical Western Pacific (TWP) and the North Slope Alaska (NSA) sites. The three ARM sites are expected to be dependable sources of high quality radiometric data along with coincident atmospheric soundings and cloud data. It is critical that the collection of this ground-based data be coordinated temporally and spatially with the collection of the space-borne CERES instrument measurements.

4.6.4.2 Other Post-launch Activities

As currently formulated, the validation of CERES subsystem 4.6 does not require additional EOS-targeted coordinated field campaigns, other satellite data, instrument development, or geometric registration sites.

4.6.4.3 New EOS-targeted Coordinated Field Campaigns

None beyond the needs of SARB (CERES subsystem 5.0)

4.6.4.4 Needs for Other Satellite Data

None beyond the needs of SARB (CERES subsystem 5.0)

4.6.4.5 Measurement Needs

It is important that comprehensive observations be made for as many of the potentially relevant parameters as possible. Further data useful for post-launch validation should be available through the NOAA Integrated Surface Irradiance Study (ISIS), which utilizes surface fluxes measured by the NOAA Surface Radiation (SURFRAD) network in the U.S. and by the World Climate Research Program (WCRP) Baseline Surface Radiation Network (BSRN) at selected sites around the Earth. Unlike the ARM sites, however, coincident meteorological data may not be available from the SURFRAD and the BSRN sites. Thus, data from other sources will be required to fill the information gap. In addition, information concerning surface shortwave and longwave optical properties will be provided by helicopter surveys. Such helicopter surveys will complement both TOA and ground-based measurements and thereby help in the detection of thin cirrus, aerosol layers, etc. It is further anticipated that high quality radiometric measurements useful for post-launch validation will be provided by an array of instruments located at the Chesapeake Lighthouse that is operated by NASA/LaRC. Possibly the most critical, yet most elusive, surface measurements involve the acquisition of net surface fluxes representative of the CERES single satellite footprint. Such measurements, if coincident with TOA radiance measurements, would prove invaluable in ascertaining the accuracy of the ATBD 4.6 algorithms. Though, the technical problems involved with obtaining such measurements may preclude adequate coverage of measured net surface fluxes.

4.6.4.6 Needs for Instrument Development

None

4.6.4.7 Geometric Registration Site

None

4.6.4.8 Intercomparisons

For both the shortwave and longwave portions of the spectrum the CERES subsystem 4.6 algorithms provide direct relationships between the measured TOA radiances and the surface fluxes. This contrasts with the CERES subsystem 5.0 algorithms that utilize complex physical models to obtain the surface fluxes from surface and atmospheric parameters only. Because both subsystems produce surface fluxes using CERES instrument TOA radiances, the results will be intercompared to check for consistency and to improve the accuracy of both sets of algorithms.

4.6.5 Implementation of Validation Results

4.6.5.1 Approach

The process for validating the CERES ATBD 4.6 radiative transfer algorithms is as follows. Total, Shortwave and Window channel TOA fluxes, derived from corresponding CERES measured radiances and suitably validated angular distribution models, will be collected for regions corresponding to the available surface validation sites. Simultaneously measured surface fluxes will then be collected at the surface validation sites for both broadband shortwave and longwave portions of the spectrum. In addition, corresponding measurements of the atmospheric temperature and total column water vapor will be obtained. The Li *et al*. (1993a) shortwave algorithm and the Inamdar and Ramanathan (1994) longwave algorithm will then be applied to the TOA fluxes to obtain net surface fluxes. The Gupta (1989) longwave algorithm will derive the net surface flux directly from the meteorological data.

With regard to the shortwave algorithm, direct comparisons can be made between satellite derived surface fluxes and surface based measurements whenever net surface fluxes are available (e.g., ARM sites). Frequently, however, the upwelling solar flux is not measured, and thus only a value for the insolation is available. As a consequence, the satellite derived net surface flux must be converted into an equivalent insolation. Li and Garand (1994) successfully developed an algorithm to make the conversion from net shortwave surface fluxes to insolation, though only for clear sky conditions. While useful, the Li and Garand (1994) algorithm does not properly address cloudy sky conditions and thus cannot be applied to solving the question of enhanced shortwave absorption for cloudy skies. In contrast, the Langley Parameterized Shortwave Algorithm (LPSA) has been developed for all sky conditions (Staylor and Wilber, 1990, and Gupta *et al.*, 2000). A study by Cess *et al.* (1996), however, raised important questions regarding the validity of the formulation reported by Staylor and Wilber (1990). To address the concerns directed at the LPSA, the surface-only working group has been actively pursuing an endeavor to extensively test, thoroughly document, and appropriately modify the LPSA. With regards to the concerns of the Cess *et al.* (1996) report, we have rederived from first principles the formula for the mean cosine of the solar zenith angle, and incorporated this correction into the LPSA. The goal is to create a reliable model to translate net shortwave fluxes into insolation for all sky conditions. In addition, an advanced version of the Li *et al*. (1993a) shortwave algorithm (Masuda *et al*., 1995) will be tested and implemented if warranted.

Preliminary results of our validation efforts for the Li *et al.* (1993a) shortwave algorithm are presented in Fig. 1 for the clear sky conditions during the month of April, 1998. Since only insolation measurements were available at the surface, we used the Li and Garand (1994) algorithm (Model A) and the LPSA (Gupta *et al.*, 2000) algorithm (Model B) to calculate the insolation from the net shortwave fluxes provided by the Li *et al.* (1993a) shortwave algorithm. During the process of our analysis, a significant number of problems were uncovered. Some of the problems, such as the scene-type mismatch for Mauna Loa, are easily understood and corrected. Other problems, such as instrument failures, can be quite insidious. It is anticipated, however, that once CERES edition 1 data becomes available, a clearer understanding from the comparisons will become available. One result which has become clear is that Model A is always biased high with respect to Model B.

Validating the Inamdar and Ramanathan (1994) longwave algorithm begins with the acquisition of broadband longwave TOA fluxes derived from CERES TOA Total and Shortwave channel fluxes, and the acquisition of the 8 to 12 μm TOA fluxes derived from the CERES TOA Window channel. The Inamdar and Ramanathan (1994) longwave algorithm will also input the total column precipitable water vapor from the SSM/I (Special Sensor Microwave Imager) as provided through MOA. The Inamdar and Ramanathan algorithm will then use the input information to derive net surface fluxes, which in combination with the Wilber *et al.* (1999) surface emissivity maps will allow for comparisons to the measured longwave surface fluxes.

The Gupta (1989) longwave algorithm derives surface fluxes directly from the meteorological data available through MOA and the surface emissivity maps developed for CERES (Wilber *et al.*, 1999). For the validation of this algorithm, CERES-derived downward and net longwave fluxes will be extracted over the SGP, TWP, and NSA ARM sites. Similar data will also be extracted over all BSRN sites where surface data are available during and after 1998. Radiometric data from six BSRN sites are already available from the archives. Validations will be done in the form of scatter plots and time series. Results from the validation effort will allow for improvements in the parameterization used to derive the CERES data.

Preliminary results of our validation efforts for the Gupta (1989) longwave algorithm are presented in Fig. 2 for the all sky conditions during the month of April, 1998. The results are very encouraging; however, again a clearer understanding of the comparisons awaits the release of the CERES edition 1 data.

After the radiative transfer algorithms are applied to a sufficient number of derived TOA fluxes to simulate the surface fluxes to be compared with the measured surface fluxes, a thorough error analysis can be undertaken to analyze the results of the comparisons. This analysis is intended to provide sufficient information so that a determination can be made regarding the suitability of the radiative transfer algorithms.

Each of the CERES 4.6 radiative transfer algorithms have already undergone substantial pre-launch comparisons. The validation process being undertaken with the CERES data should provide the user sufficient confidence in the application of these radiative transfer algorithms. Note, that even during the post-launch sequence of activities, we will continue validation so as to insure the quality of the resultant surface fluxes

4.6.5.2 Role of EOSDIS

None

4.6.5.3 Plans for Archival of Validation Data

The results of these validation tests will then be archived at the Atmospheric Sciences Data Center (ASDC) at NASA/LaRC.

4.6.6 Summary

Output Data Parameters: Net shortwave surface flux; Clear-sky downward longwave ($\lambda > 5.0\ \mu m$), window (8.0—$12.0\ \mu m$) and non-window surface fluxes (Wm^{-2}); and Total-sky downward and net longwave surface fluxes.

Validation Criteria: Root mean square errors of $\pm$ 20 Wm^{-2} for instantaneous retrievals and $\pm$ 10 Wm^{-2} for gridded monthly averages for both shortwave and longwave surface fluxes.

Validation Data Sources: A limited validation data set has been produced from measurements taken at the ARM/CART Southern Great Plains (SGP) site, and is available through the CERES/ARM/GEWEX experiment (CAGEX) at NASA/LaRC. The CAGEX database provides measurements taken at the SGP site concerning surface shortwave and longwave fluxes. It is anticipated that collection of high quality surface measurements will continue at the SGP site and will be initiated at the Tropical Western Pacific (TWP) and the North Slope Alaska (NSA) sites. Further data useful for validation should be available through the NOAA Integrated Surface Irradiance Study (ISIS), which utilizes surface fluxes measured by the NOAA Surface Radiation (SURFRAD) network in the U.S. and by the World Climate Research Program (WCRP) Baseline Surface Radiation Network (BSRN) at selected sites around the globe. Finally, a compilation of CERES and ARM data sets, known as CAVE, will be made available by the CERES subsystem 5.0 validation effort.

Validation Procedure: The validation of the CERES ATBD 4.6 parameterized radiative transfer algorithms will proceed by gathering the necessary input data (simultaneously measured TOA and net surface fluxes for both the shortwave and longwave portions of the spectrum, atmospheric temperature and total column water vapor); applying the radiative transfer algorithms to the measured TOA data to derive simulated surface radiation fluxes which are then compared with the measured surface radiation fluxes; followed by a thorough error analysis to the results of these comparisons.

Validation Archive: Validation data and results will be made available through anonymous ftp and/or through the World Wide Web.

4.6.7 References

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4.6.8 Figure Captions

Figure 1. Comparison of the downward shortwave flux at the surface from the CERES SSF data derived by the Li *et al*. (1993b) algorithm to the insolation measured by the ground based instruments. To calculate the insolation from the net shortwave flux, Model A uses the Li and Garand (1994) algorithm, while Model B uses the LPSA (Gupta *et al*., 2000) algorithm.

Figure 2. Comparison of the downward longwave flux at the surface calculated by the Gupta *et al*. (1994) algorithm to the downward longwave flux measured by the ground based instruments.

Figure 1

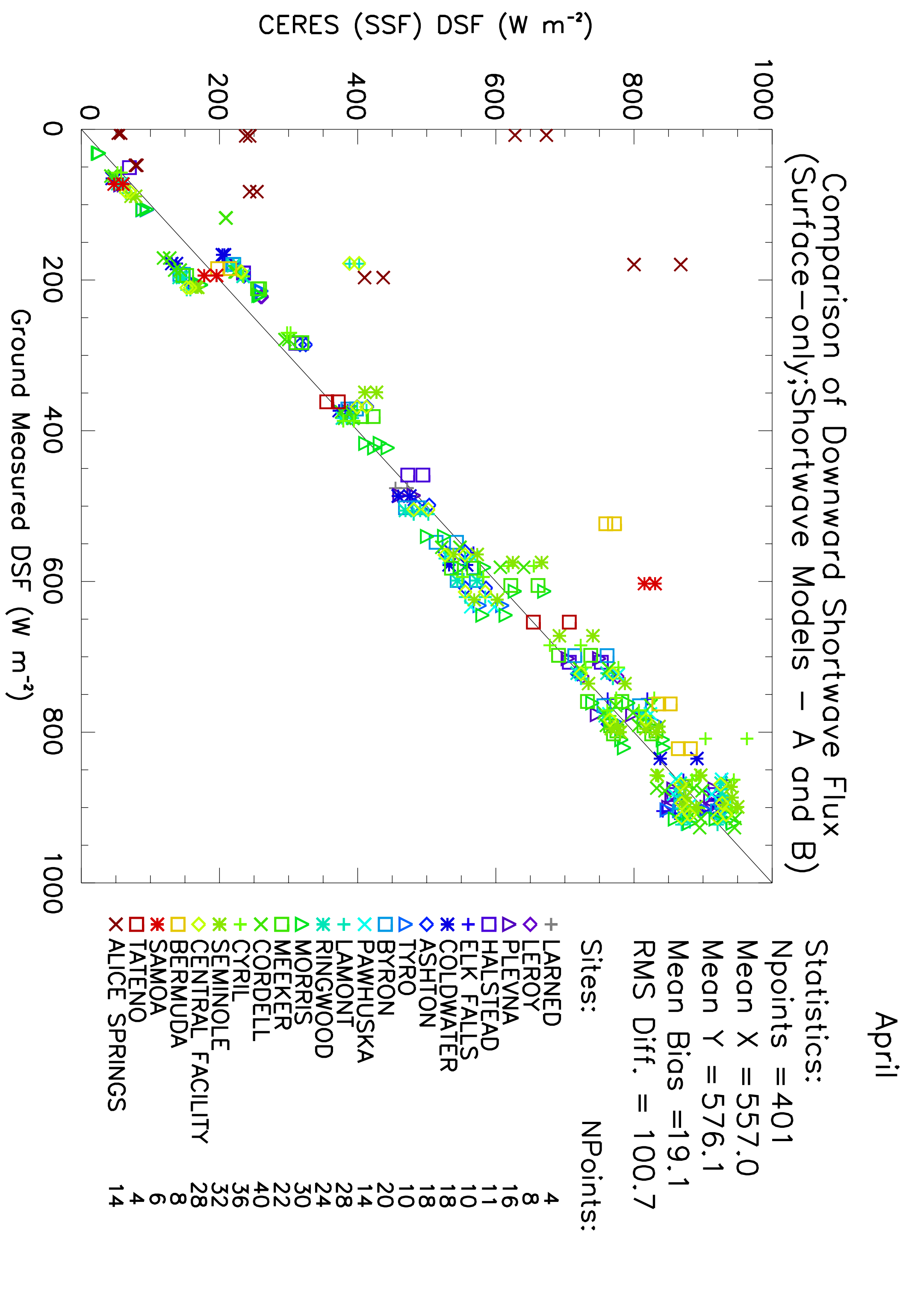
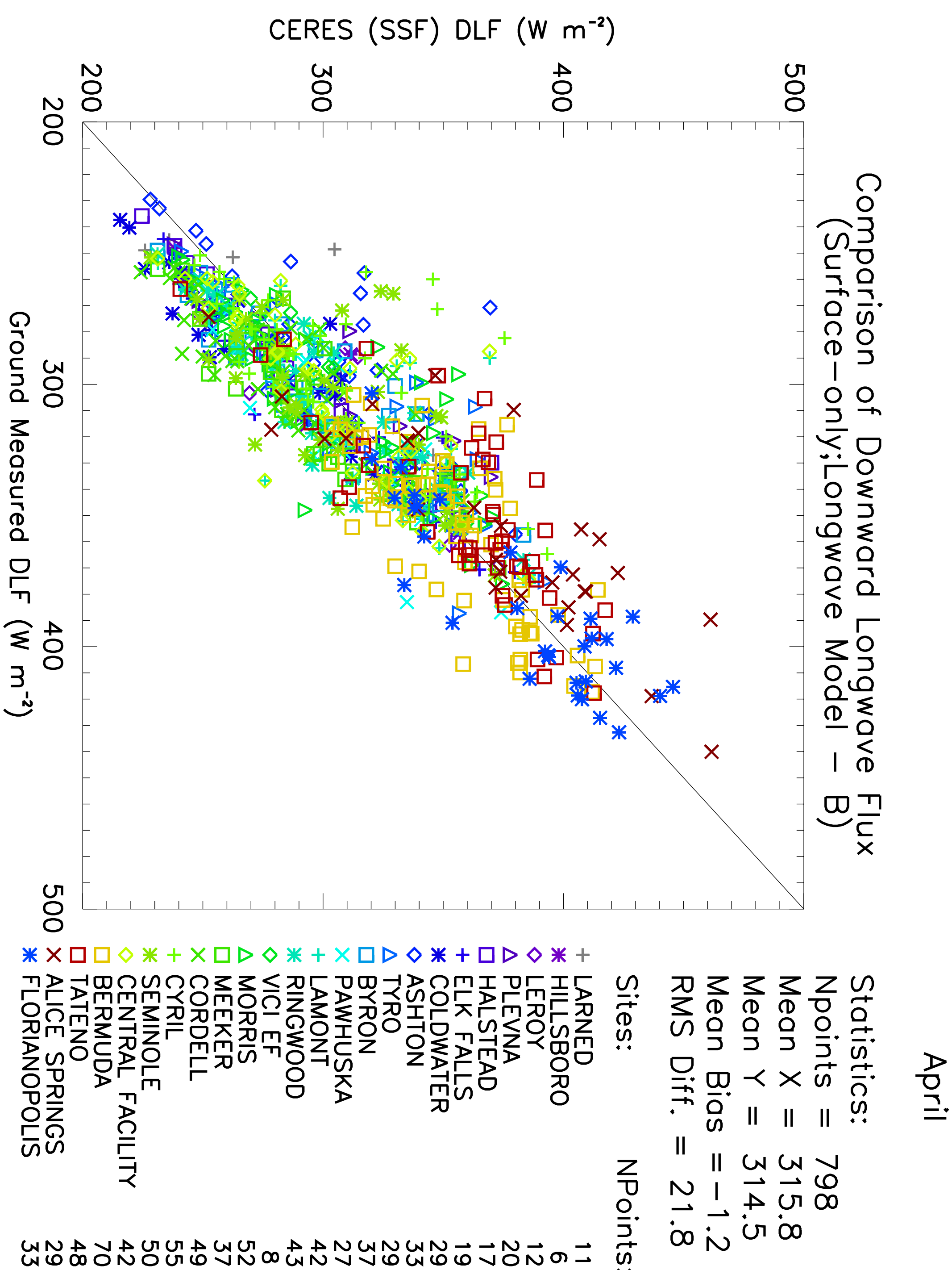

Comparison of Downward Shortwave Flux
(Surface–only;Shortwave Models – A and B)
CERES (SSF) DSF (W m⁻²)
Ground Measured DSF (W m⁻²)
0
200
400
600
800
1000
April
Statistics:
Npoints =401
Mean X =557.0
Mean Y =576.1
Mean Bias =19.1
RMS Diff. = 100.7
Sites: NPoints:
LARNED 4
LEROY 8
PLEVNA 16
HALSTEAD 11
ELK FALLS 10
COLDWATER 18
ASHTON 18
TYRO 10
BYRON 20
PAWHUSKA 14
LAMONT 28
RINGWOOD 24
MORRIS 30
MEEKER 22
CORDELL 40
CYRIL 36
SEMINOLE 32
CENTRAL FACILITY 28
BERMUDA 8
SAMOA 6
TATENO 4
ALICE SPRINGS 14

Figure 2


Comparison of Downward Longwave Flux
(Surface–only;Longwave Model – B)
April
CERES (SSF) DLF (W m⁻²)
Ground Measured DLF (W m⁻²)
200
300
400
500
Statistics:
Npoints = 798
Mean X = 315.8
Mean Y = 314.5
Mean Bias = –1.2
RMS Diff. = 21.8
Sites: NPoints:
LARNED 11
HILLSBORO 6
LEROY 12
PLEVNA 20
HALSTEAD 17
ELK FALLS 19
COLDWATER 29
ASHTON 33
TYRO 29
BYRON 37
PAWHUSKA 27
LAMONT 42
RINGWOOD 43
VICI EF 8
MORRIS 52
MEEKER 37
CORDELL 49
CYRIL 55
SEMINOLE 50
CENTRAL FACILITY 42
BERMUDA 70
TATENO 48
ALICE SPRINGS 29
FLORIANOPOLIS 33